U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-290 946

Air Emissions from Combustion of Solvent Refined Coal

Hittman Associates, Inc, Columbia, MD

Prepared for

Industrial Environmental Research Lab, Research Triangle Park, NC

Jan 79

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

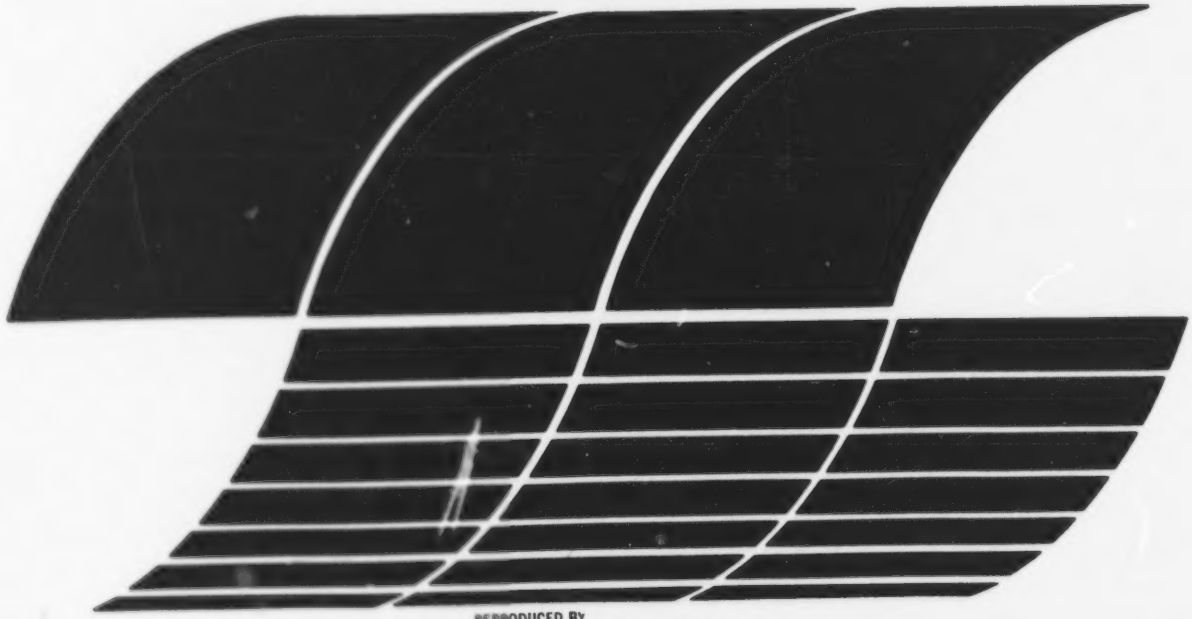
EPA-600/7-79-004
January 1979

PB 290946

EPA

Air Emissions from Combustion of Solvent Refined Coal

Interagency Energy/Environment R&D Program Report



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

This report has been reviewed by the participating Federal Agencies, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-004	2.
3. RECIPIENT'S ACCESSION NO. PB290946	
4. TITLE AND SUBTITLE Air Emissions from Combustion of Solvent Refined Coal	5. REPORT DATE January 1979
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kenneth G. Budden and Subhash S. Patel	8. PERFORMING ORGANIZATION REPORT NO. HIT-C165/860-78-733D2
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hittman Associates, Inc. 9190 Red Branch Road Columbia, Maryland 21045	10. PROGRAM ELEMENT NO. EHE623A
	11. CONTRACT/GRANT NO. 68-02-2162
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED Task Final; 3/77 - 9/78
	14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is William J. Rhodes, MD-61, 919/541-2851.

16. ABSTRACT The report gives details of a Solvent Refined Coal (SRC) combustion test at Georgia Power Company's Plant Mitchell, March, May, and June 1977. Flue gas samples were collected for modified EPA Level 1 analysis; analytical results are reported. Air emissions from the combustion of coal and SRC are compared for various organic and inorganic constituents, and SO2 and NOx. The impact of the air emissions from the combustion of SRC is assessed by comparison with EPA's Multimedia Environmental Goals and existing New Source Performance Standards. Air quality emissions test data indicated that SRC SO2 and NOx emissions were 1.06 and 0.43 lb/million Btu, respectively; or about 12 and 39% under the existing NSPS of 1.2 lb/million Btu for SOx and 0.7 lb/million Btu for NOx. If the SO2 standard is reduced, SRC derived from high sulfur coal may not meet the new standard. The low NOx emissions may be a result of the abnormally high excess air that was used during the test: additional testing at normal conditions is required. Particulate emissions can probably be controlled well below the EPA standard of 0.1 lb/million Btu by installing a modern ESP, with a particulate collection efficiency of about 95%.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Nitrogen Oxides	Air Pollution Control	13B	07B
Coal	Sulfur Oxides	Stationary Sources	21D	
Liquefaction	Dust	Solvent Refined Coal	07D	11G
Combustion		Particulate	21B	
Flue Gases				
Analyzing			14B	

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 48
	20. SECURITY CLASS (This page) Unclassified	22. PRICE A03 - A01

EPA Form 2220-1 (9-73)

EPA-600/7-79-004

January 1979

Air Emissions from Combustion of Solvent Refined Coal

by

Kenneth G. Budden and Subhash S. Patel

Hittman Associates, Inc.
9190 Red Branch Road
Columbia, Maryland 21045

Contract No. 68-02-2162
Program Element No. EHE623A

EPA Project Officer: William J. Rhodes

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

1a

ABSTRACT

This report details the air emissions associated with the Solvent Refined Coal (SRC) combustion test, conducted at Georgia Power Company's Plant Mitchell, during the months of March, May, and June, 1977. A larger study and evaluation of SRC combustion test is being done by the Department of Energy and its contractors. The purpose of the test was to determine whether SRC is an acceptable substitute for coal, and to demonstrate the assumed advantages of SRC. The test was conducted in three phases, with coal being fired during the first and second phases, and SRC during the third. Flue gas samples were collected for modified U.S. Environmental Protection Agency (EPA) Level I analysis, and analytical results are reported. Air emissions from the combustion of coal and SRC are compared for various organic and inorganic constituents, and SO_2 and NO_x. Finally, the impact of the air emissions from the combustion of SRC is assessed by comparison with EPA's Multimedia Environmental Goals and existing New Source Performance Standards.

Air quality emissions test data indicated that SRC SO_2 and NO_x emissions were 0.46 and 0.19 kg/GJ (1.06 and 0.43 $lb/10^6$ Btu) respectively. This is about 12 and 39 percent under the existing New Source Performance Standards (NSPS) of 0.52 kg/GJ (1.2 $lbs/10^6$ Btu) for SO_x and 0.30 kg/GJ (0.7 $lbs/10^6$ Btu). If the SO_2 standard is reduced to 0.26 kg/GJ (0.6 $lbs/10^6$ Btu), SRC derived from high sulfur coal may not meet this standard. The low NO_x emissions may be a result of abnormally high excess air that was used during the combustion test and additional testing at normal conditions is required.

Particulate emissions can be controlled well below the EPA standard of 0.04 kg/GJ (0.1 $lbs/10^6$ Btu) by installing a modern precipitator having a particulate collection efficiency of approximately 95 percent.

CONTENTS

Abstract..... ii
Figures and Tables..... iv
List of Abbreviations and Symbols..... vi
Acknowledgement vii

1. Introduction..... 1
2. Conclusions and Recommendations..... 4
3. Combustion Test..... 5
    Sample collection..... 6
    Sampling locations..... 7
    Sampling schedule..... 8
4. Analyses..... 10
    Grab samples..... 10
    SASS train samples..... 10
5. Comparison of Air Emissions..... 27
    Organics..... 27
    Inorganics..... 28
    SO_2 and NO_x..... 29
6. Assessment of Air Emissions..... 32
    Organics..... 32
    Inorganics..... 32
    SO_2 and NO_x..... 34

Bibliography..... 37

FIGURES AND TABLES

Figure Number		Page
1	SASS Train Flowsheet	6
2	Diagram of Sampling Locations	8
3	Analytical Procedures Followed in SASS Train Run Analysis	15
4	MEG Chart, November 1977 Version	33

Table Number		Page
1	Phase II - Coal Combustion Test Sampling Schedule	9
2	Phase III - SRC Coal Combustion Test Sampling Schedule	9
3	On-Site Analysis of Grab Samples, Phase II - Coal Combustion	11
4	On-Site Analysis of Grab Samples, Phase III - SRC Combustion	12
5	Combustion Test, Phase II - Coal Samples	13
6	Combustion Test, Phase III - SRC Samples	13
7	Process Information	14
8	GC Analysis for C_7 through C_{16} Hydrocarbons	16
9	IR Examination of Nonvolatile Hydrocarbons, June 16, 1977	18
10	IR Examination of Nonvolatile Hydrocarbons, June 19, 1977	18

Table Number		Page
11	Total Hg, As, and Sb in Particulates and XAD-2 Resin Samples.	19
12	SSMS Elemental Analysis of SASS Train Samples. .	20
13	SSMS Analysis of SRC Sample	22
14	Elements Selected for Part II Inorganic Analysis	23
15	Process Information	24
16	GC Analysis for C_7 through C_{12} Hydrocarbons . .	25
17	AA Analysis for Inorganics	26
18	Organic Air Emissions for Coal and SRC	28
19	Inorganic Air Emissions for Coal and SRC	29
20	SO_2 and NO_x Emissions for Coal and SRC	30
21	Comparison of SRC Air Emissions with MEG's . . .	35

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

AA	-- atomic absorption spectrophotometry
Btu	-- british thermal unit
CFM	-- cubic feet per minute
DSCF	-- dry standard cubic feet
EOD	-- elimination of discharge
EPC	-- estimated permissible concentrations
ESP	-- electrostatic precipitator
GC	-- gas chromatography
GC/MS	-- gas chromatography/mass spectrometry
IR	-- infrared spectra
kg/GJ	-- kilogram per giga (10^9) joules
LRMS	-- low resolution mass spectrometry
MATE	-- minimum acute toxicity effluents
MC	-- mass constituent
MEG	-- multimedia environmental goals
MJ/kg	-- mega joules per kilogram
MW	-- megawatt
m^3	-- cubic meter
mg	-- milligram
ml	-- milliliter
mg/m^3	-- milligram per cubic meter
nm	-- nanometer
PAH	-- polynuclear aromatic hydrocarbon
ppb	-- parts per billion
ppm	-- parts per million
SASS	-- source assessment sampling system
SRC	-- solvent refined coal
SSMS	-- spark source mass spectrometry

SYMBOLS

As	-- arsenic
C	-- carbon
CH_2Cl_2	-- methylene chloride
CO	-- carbon monoxide
CO_2	-- carbon dioxide
Hg	-- mercury
NO_x	-- nitrogen oxides
Sb	-- antimony
SO_2	-- sulfur dioxide
μ	-- micron
$\mu g/g$	-- microgram per gram
$\mu g/m^3$	-- microgram per cubic meter

ACKNOWLEDGMENT

We gratefully acknowledge the contributions made to this report by the following individuals: Richard McRanie and Robert Gehri of Southern Company Services; Walter Dixon of Southern Research Institute; Richard Corey of Department of Energy; and Mike Hartman, Arnie Grant and Carol Zee of TRW.

SECTION 1

INTRODUCTION

The U.S. has more energy available in the form of coal than in the combined resources of petroleum, natural gas, oil shale, and tar sands. In light of nationwide energy shortages, the increased use of our abundant coal reserves is vital to the nation's total supply of clean energy. Consequently, converting coal to liquid and gaseous fuels is fundamental to ensuring the availability of fuel as these alternate sources become less certain.

The primary users of coal are the electric utilities, which mechanically clean, pulverize and burn coal in solid form. Coal combustion, however, is a major source of air pollution, i.e., sulfur oxides, nitrogen oxides, and particulate matter. The combustion of coal by electric utilities is also a potential source of water and land pollution.

To minimize air pollution from the combustion of coal by electric utilities, the Solvent Refined Coal Process is being developed. This process cleans coal prior to its firing in boilers by the removal of sulfur and mineral matter, for the purpose of eliminating the need for stack gas cleaning. The product, Solvent Refined Coal (SRC), is lower in sulfur and ash, and has a higher heating value than the original coal.

In 1972 an all-industry group, presently consisting of Electric Power Research Institute and Southern Company Services, initiated a pilot plant project to study the technological feasibility of the SRC process. Operating information from this pilot plant was used to design and build a 45 metric ton per day pilot plant in Fort Lewis, Washington. This project funded by the U.S. Department of Energy (DOE) is developed by Pittsburgh & Midway Coal Mining Company, a subsidiary of Gulf Oil Corporation. The pilot plant has been in operation since October 1974 and has produced 2,720 metric tons of SRC for the functional product testing in a boiler.

With the company's involvement in developing the SRC process, Southern Company Services was awarded a separate

contract by DOE to evaluate the shipping, handling, and burning characteristics of SRC. To determine whether SRC can be an acceptable substitute for coal and to demonstrate the assumed advantages of SRC a combustion test was performed in March, May and June of 1977 at Georgia Power Company's Plant Mitchell. The test was conducted in three phases and marked the first time SRC had been burned, on a large scale, in a conventional utility boiler.

In Phase I, low sulfur Kentucky coal was burned in an existing, unmodified 22.5 MW pulverized coal boiler. In Phase II, following replacement of the original burners with dual register burners and accompanying modifications, the boiler was again fired with low sulfur Kentucky coal. In Phase III, following adjustment of the burners and pulverizers, SRC was burned. The SRC had been produced at the Fort Lewis pilot plant from western Kentucky coals having a sulfur content of approximately 4 percent and an ash content of 10 to 12 percent. Sulfur and ash in the SRC were nominally 0.7 and 0.6 percent respectively. In each of the three phases, the boiler was operated at full (~21 MW), medium (~14 MW), and low (~7 MW) load conditions. Phases II and III are discussed in detail in this report.

During Phases II and III, flue gas sampling was conducted using a Source Assessment Sampling System (SASS) train to collect samples for modified EPA Level 1 laboratory analysis. Grab samples were also obtained for on-site analysis of C_1 through C_6 hydrocarbons, SO_2, N_2, CO, CO_2 and O_2. Sampling and analysis are discussed in detail in later sections of this report.

Participants in the combustion test included:

- Southern Company Services - co-sponsor and owner
- DOE (formerly ERDA) - co-sponsor and supplier of SRC
- Southern Research Institute (SRI) - SASS train sampling and resistivity tests
- TRW - grab sampling and on-site analysis for CO, CO_2, SO_2, N_2, O_2 and C_1 through C_6 hydrocarbons
- York Research - EPA-5 and ASME trains, gaseous emissions, and precipitator efficiency
- Babcock & Wilcox - boiler efficiency
- Rust Engineering (a subsidiary of Wheelabrator-Frye) - resistivity tests

- Wheelabrator-Frye - precipitator modeling for control of SRC combustion particulates

- Hittman Associates, Inc. - development and coordination of SASS train and grab sampling plan, sample analysis, and interpretation

The results of the tests concerning resistivity, and precipitator and boiler efficiencies, are not discussed in this report. The EPA sponsored precipitator evaluation as a supplement to the DOE plan is presented in "Evaluation of Electrostatic Precipitator During SRC Combustion Tests," EPA-600/7-78-129, June 1978.

The results of the emissions measurement work performed by York Research Corporation under contract to Southern Company Services, Inc., will be incorporated in a report being prepared by Southern Company Services, Inc.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The results of the combustion test at Plant Mitchell indicated that SRC can be combusted in place of coal to fuel today's utility boilers. No major operational problems were encountered during the firing of SRC.

Significant reductions in SO_2, NO_x, and inorganic emissions were observed. During combustion of SRC, SO_2 emissions were reduced to compliance with the existing New Source Performance Standards (NSPS) of 0.52 kg/GJ (1.2 lbs/10^6 Btu) input. If, however, this standard is reduced to 0.26 kg/GJ (0.6 lb/10^6) Btu, as is currently being contemplated by the U.S. Environmental Protection Agency (EPA), compliance is doubtful.

NO_x emissions were well below the NSPS of 0.3 kg/GJ (0.7 lbs/10^6 Btu). NO_x concentrations increase with increase in excess air but use of abnormally high excess air has an effect of lowering NO_x emissions. During the combustion test abnormally high excess air was used, and it is therefore recommended that additional testing should be conducted at normal conditions.

The electrostatic precipitator used throughout the test was an old (1946) Research Cottrell unit which was inefficient for SRC flyash collection (16.89 to 45.68 percent). When a more modern precipitator was briefly tested, collection efficiency increased to approximately 95 percent. It is therefore recommended that additional testing be conducted, using a more efficient precipitator, to provide a more accurate account of actual atmospheric particulate emissions associated with the combustion of SRC.

SECTION 3

COMBUSTION TEST

One of the primary purposes of the combustion test was to demonstrate the assumed advantages of SRC as a boiler fuel. This was attempted by retrofitting a small utility boiler and burning approximately 2,722 metric tons of SRC under carefully measured conditions. The work was regarded as a significant milestone in the objective of qualifying coal-derived fuels for future energy needs.

The unit selected for the test, Boiler No. 1, is located at Georgia Power Company's Plant Mitchell, near Albany, Georgia, and has a nameplate rating of 22.5 MW. The Babcock & Wilcox (B&W) natural circulation pulverized coal-fired boiler is rated at 104,320 kilograms of steam per hour at 58 atmospheres and 480°C. The unit is equipped with B&W E-35 pulverizers and a Research Cottrell perforated plate electrostatic precipitator. Turbines and generators were manufactured by General Electric.

The test was conducted in a three-phase program. During Phase I, low sulfur (~1 percent) Kentucky coal was burned in the unmodified boiler. The purpose of this phase was to provide a data base to isolate the effects of the changed boiler configuration used during Phase II. All pulverizers, burners, and controls were operated normally. SASS train samples were not collected during this phase.

Once again burning low sulfur (~1 percent) Kentucky coal, Phase II was initiated May 24, 1977 and concluded June 6, 1977. The original burners were replaced prior to this phase with dual register burners and accompanying modifications. This phase was to establish a base-line of operation for later comparison with Phase III results. The pulverizers and controls were operated normally. SASS train and grab samples were collected throughout this phase.

Phase III began June 10, 1977 and continued through June 25, 1977. Solvent Refined Coal I, which had been produced at the Fort Lewis pilot plant in Washington, was fired. The SRC had been produced from western Kentucky coals having a sulfur content of approximately 4 percent and an ash content of 10 to 12 percent. Minor modifications

were made to the pulverizers and dual register burners. The purpose of this phase was to demonstrate the assumed advantages of SRC as a boiler fuel. SASS train and grab samples were also collected during this phase.

SAMPLE COLLECTION

SASS Train

During Phases II and III, flue gas sampling was conducted using SASS train and grab samples for modified EPA Level I laboratory analysis. Grab samples were obtained for on-site analysis of C_1 through C_6 hydrocarbons, SO_2, N_2, CO, CO_2 and O_2.

A diagram of the SASS train is shown in Figure 1. This sampling device includes cyclones and a filter to collect particulates, a sorbent trap to collect organic constituents, impingers, and associated temperature controls, pumps, and meters. The sample is obtained from the flue gas duct by means of a probe inserted through the duct work and positioned to intersect the gas flow at a point having flow characteristics representative of the bulk flow.

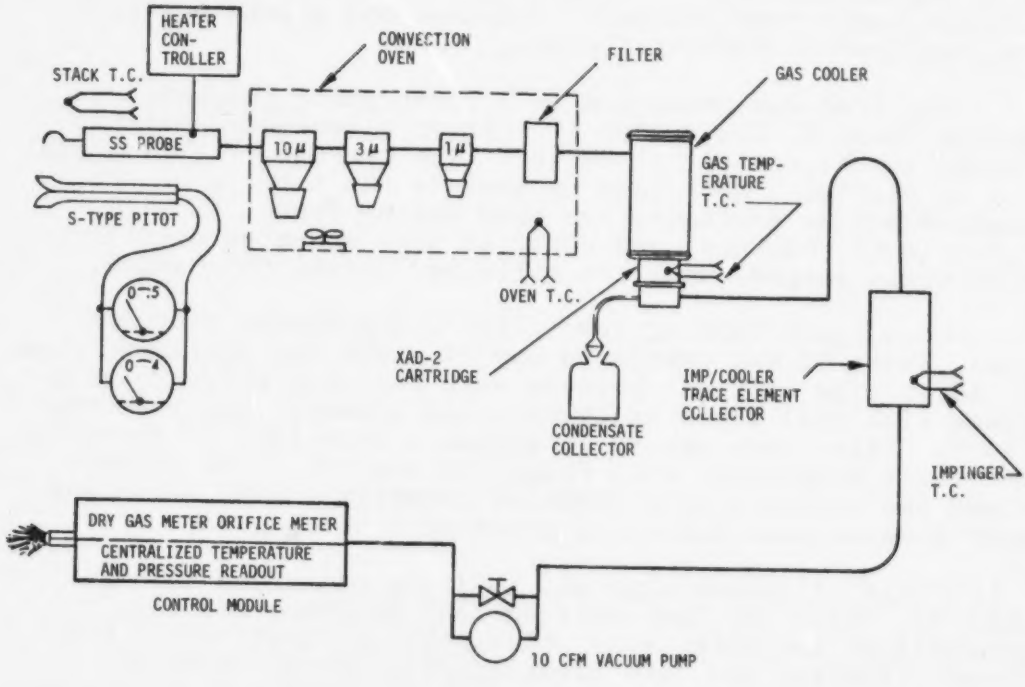


Figure 1. SASS Train Flowsheet

Particulates were removed from the sample flue gas first, when the gas passed through a series of cyclones maintained at 205°C. Particulates were collected in three size ranges, >10μ, 3 to 10μ, and 1 to 3μ. A standard fiberglass filter following the cyclones collected a fourth size range, <1μ.

Gas leaving the filter was cooled to approximately 20°C and was passed through a cartridge containing XAD-2 resin. This resin absorbed a broad range of organic compounds. Condensate produced when the gas was cooled was collected in a condensate trap.

A series of three impingers followed the resin cartridge. The first contained a hydrogen peroxide solution, which removed reducing components to prevent deterioration of the remaining impinger solutions. The second and third impingers, containing ammonium persulfate and silver nitrate, collected volatile inorganic trace elements.

Next, the gas passed through a dehydrating agent in order to protect the pump, which followed. Finally, the gas flow rate was metered and the gas vented.

Using the SASS train, each sample run provided a total of nine samples, all of which included solids fractions, condensate, resin, impinger liquids, and rinses.

Grab Samples

Flue gas grab samples were collected using a Tedlar bag and a stainless steel probe. The samples were extracted from the duct by means of a peristaltic pump, which can obtain leak-free samples over a long period of time.

Daily composites of the coal and SRC fired during the test were also collected.

SAMPLING LOCATIONS

Figure 2 depicts the location of the sampling ports used throughout the test. Boiler No. 1 was fired during all phases of the test. SASS train and grab samples were collected either at inlet port A or outlet port B. Point X indicates the location of a continuous sampler for monitoring SO_2 and NO_x.

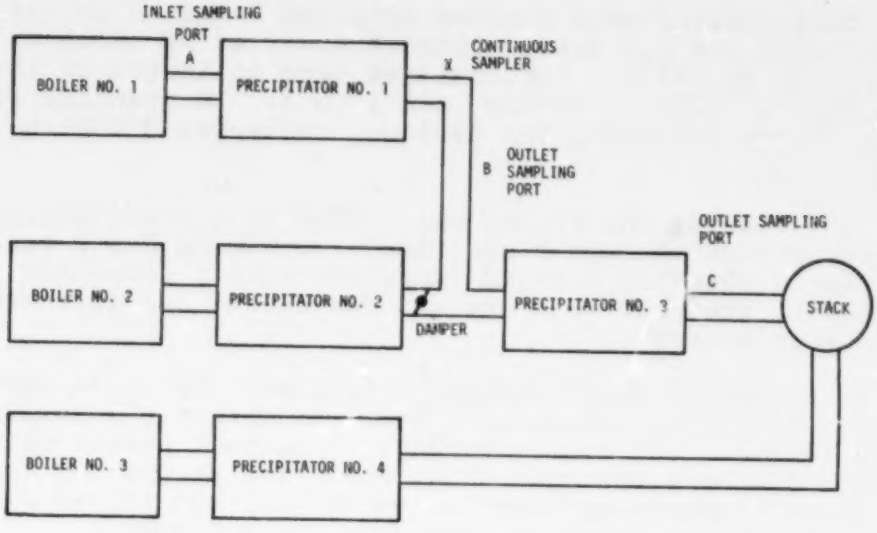


Figure 2. Diagram of Sampling Locations

Since precipitator No. 1 is a vintage Research Cottrell unit, it was requested that additional tests be performed on precipitator No. 3, a newer unit, for modeling purposes. To facilitate these tests, boiler No. 2 and precipitators No. 1 and No. 2 were shut down, and SASS train and grab samples were collected at outlet port C.

SAMPLING SCHEDULE

The schedules for test Phases II and III were developed by Southern Company Services after consultation with the participants. The boiler load condition and test precipitator were designated for each day of the test. Tables 1 and 2 indicate these schedules as well as the location for SASS train and grab samples.

Because only one SASS train was available, it was impossible to simultaneously collect samples at both the inlet and outlet ports of the precipitator. During each phase the SASS train location was varied to permit sampling at both ports A and B. SASS train and grab samples were collected from the same locations.

TABLE 1. PHASE II - COAL COMBUSTION TEST SAMPLING SCHEDULE

Date	Load Condition	SASS Train Sampling Location
May 24	Full	Outlet ESP #1
May 25	Medium	Outlet ESP #1
May 26	Low	Outlet ESP #1
May 27	Full	Outlet ESP #1
May 28	Full	Inlet ESP #1
May 29	Medium	Inlet ESP #1
May 30	Medium	Outlet ESP #1
May 31	Low	Outlet ESP #1
June 1	Low	Inlet ESP #1
June 5	Full	Outlet ESP #3
June 6	Full	Outlet ESP #3

TABLE 2. PHASE III - SRC COAL COMBUSTION TEST SAMPLING SCHEDULE

Date	Load Condition	SASS Train Sampling Location
June 13	Full	Outlet ESP #1
June 14	Medium	Outlet ESP #1
June 15	Low	Outlet ESP #1
June 16	Full	Outlet ESP #1
June 17	Full	Inlet ESP #1
June 18	Low	Inlet ESP #1
June 19	Low	Outlet ESP #1
June 20	Medium	Inlet ESP #1
June 21	Medium	Outlet ESP #1
June 22	Full	Outlet ESP #3
June 23	Full	Outlet ESP #3
June 24	"wide open"	Outlet ESP #1

SECTION 4

ANALYSES

GRAB SAMPLES

Flue gas grab samples were analyzed for C_1 through C_6 hydrocarbons, SO_2, N_2, CO, CO_2, and O_2, usually within 30 minutes after sample collection. The C_1 through C_6 hydrocarbons were determined by means of a flame ionization detector in a Perkin-Elmer gas chromatograph. During the first three days of Phase II, the detection limit was 5 ppm due to improper grounding of the instrument. During the remainder of Phases II and III, the detection limit was 0.5 ppm.

The O_2, N_2, CO, CO_2, and SO_2 levels were measured with a thermal conductivity detector in an A.I.D. portable gas chromatograph. The accuracy of this instrument was $\pm$ 2 percent of the reading taken.

York Research also continuously monitored NO_x and SO_2 levels in the flue gases. Thermo Electron analyzers (Model 10 for NO_x and Model 40 for SO_2) with a reported accuracy of $\pm$ 10 ppm, were used for this purpose. The emissions measurement results will be included in a report being prepared by Southern Services, Incorporated.

Flue gas grab sample analytical results are reported in Tables 3 and 4. For comparison, typical SO_x and NO_x concentrations obtained from continuous analyzers are also given. Analytical results for coal and SRC grab samples were provided by Southern Services, Inc., and are shown in Tables 5 and 6. The coal and SRC analyses were performed by Commercial Testing and Engineering Co. of Golden, Colorado.

SASS TRAIN SAMPLES

The analysis of the SASS train samples was conducted in two parts.

TABLE 3. ON-SITE ANALYSIS OF GRAB SAMPLES, PHASE II - COAL COMBUSTION
May 24 to June 6, 1977

	On-Site Gas Chromatography Analysis										Continuous Sampler					
Date	C_1 (4)	C_2 (4)	C_3 (4)	C_4 (4)	C_5 (4)	C_6 (4)	CO (3)	O_2 (1)	CO_2 (1)	N_2 (1)	SO_x (1)	SO_x (2)	NO_x (2)	Time	Load Condition	Sample Location
5/26	ND	ND	ND	ND	ND	ND	ND	13.31%	7.40%	79.29%	254	260	110	1500	Low	O-1
5/31	ND	ND	ND	ND	ND	ND	ND	14.24%	7.50%	78.26%	329	360	110	1140	Low	O-1
6/02	ND	ND	ND	ND	ND	ND	ND	14.91%	6.56%	78.53%	174	200	100	0300	Low	I-1
5/25	ND	ND	ND	ND	ND	ND	ND	15.73%	5.51%	78.76%	413	500	170	1400	Med	O-1
5/29	ND	ND	ND	ND	ND	ND	ND	13.70%	7.59%	78.71%	209	220	160	1400	Med	I-1
5/30	ND	ND	ND	ND	ND	ND	ND	12.60%	7.35%	80.05%	413	400	150	1240	Med	O-1
5/24	--	--	--	--	--	--	--	------	-----	------	---	745	225	1200	Full	O-1
5/27	ND	ND	ND	ND	ND	ND	ND	13.78%	6.65%	79.66%	311	330	215	1530	Full	O-1
5/28	ND	ND	ND	ND	ND	ND	ND	11.25%	9.86%	78.89%	381	330	220	1420	Full	I-1
6/05	ND	ND	ND	ND	ND	ND	ND	12.14%	9.31%	78.55%	214	200	170	1330	Full	O-3
6/06	ND	ND	ND	ND	ND	ND	ND	11.16%	9.69%	79.15%	210	180	110	1030	Full	O-3

ND - None Detected

SO_x and NO_x values are in ppm

I-1 - Inlet to precipitator #1

O-1 - Outlet to precipitator #1

O-3 - Outlet to precipitator #3

(1) - $\pm$ 2% of total concentration

(2) - $\pm$ 10 ppm

(3) - 40 ppm detectable limit

(4) - 5 ppm detectable limit 5/25, 5/26, and 5/27, 0.5 ppm detectable limit 5/28 through 6/06

TABLE 4. ON-SITE ANALYSIS OF GRAB SAMPLES, PHASE III - SRC COMBUSTION
June 13 to June 24, 1977

	On-Site Gas Chromatography Analysis										Continuous Sampler					
Date	C_1 (4)	C_2 (4)	C_3 (4)	C_4 (4)	C_5 (4)	C_6 (4)	CO (3)	O_2 (1)	CO_2 (1)	N_2 (1)	SO_x (1)	SO_x (2)	NO_x (2)	Time	Load Condition	Sample Location
6/15	ND	ND	ND	ND	ND	ND	ND	14.79%	5.88%	79.33%	198	225	125	1030	Low	O-1
6/18	ND	ND	ND	ND	ND	ND	ND	13.25%	6.73%	80.02%	216	220	120	1200	Low	I-1
6/19	ND	ND	ND	ND	ND	ND	ND	14.00%	6.26%	79.74%	218	235	125	1230	Low	O-1
6/14	ND	ND	ND	ND	ND	ND	ND	13.65%	7.53%	78.82%	248	260	160	1200	Med	O-1
6/20	--	--	--	--	--	--	--	------	-----	------	---	---	---	----	Med	O-1
6/21	--	--	--	--	--	--	--	------	-----	------	---	---	---	----	Med	I-1
6/13	ND	ND	ND	ND	ND	ND	ND	11.39%	9.86%	78.75%	371	325	190	1300	Full	O-1
6/16	ND	ND	ND	ND	ND	ND	ND	10.62%	9.12%	80.26%	410	335	190	1145	Full	O-1
6/17	ND	ND	ND	ND	ND	ND	ND	11.11%	9.15%	79.74%	404	345	190	1100	Full	I-1
6/22	ND	ND	ND	ND	ND	ND	ND	11.20%	9.25%	79.55%	400	345	200	1030	Full	O-3
6/23	ND	ND	ND	ND	ND	ND	ND	10.75%	8.90%	80.35%	393	325	220	1000	Full	O-3
6/24	ND	ND	ND	ND	ND	ND	ND	10.76%	9.29%	79.95%	449	380	260	1100	23.5	O-1

ND - None Detected

SO_x and NO_x values are in ppm

I-1 - Inlet to precipitator #1

O-1 - Outlet to precipitator #1

O-3 - Outlet to precipitator #3

(1) - $\pm$ 2% of total concentration

(2) - $\pm$ 10 ppm

(3) - 40 ppm detectable limit

(4) - 0.5 ppm detectable limit

TABLE 5. COMBUSTION TEST, PHASE II - COAL SAMPLES

	Proximate Analysis		
Date	% Sulfur	% Nitrogen	Heating* Value, MJ/kg
5/26	0.64	1.38	7.144
5/31	1.05	1.81	7.043
6/2	NA	NA	NA
5/25	1.09	1.29	7.007
5/29	0.62	1.82	7.139
5/30	1.15	1.82	7.139
5/24	1.34	1.19	7.042
5/27	0.73	1.51	7.081
5/28	0.72	1.45	7.079
6/5	0.66	1.60	NA
6/6	0.64	1.81	7.143

NA - Not Available

*Moisture and Ash Free Basis

TABLE 6. COMBUSTION TEST, PHASE III - SRC SAMPLES

	Proximate Analysis		
Date	% Sulfur	% Nitrogen	Heating* Value, MJ/kg
6/15	0.70	1.54	7.530
6/18	0.74	1.80	NA
6/19	0.66	1.82	7.496
6/14	0.72	1.62	7.525
6/13	0.73	2.02	7.459
6/16	0.73	1.77	7.464
6/17	0.72	1.47	7.546
6/22	0.70	1.37	7.485
6/23	0.64	1.37	7.431
6/24	0.66	1.71	7.418

NA - Not Available

*Moisture and Ash Free Basis

Part I

In Part I, two complete SASS train runs were analyzed by TRW. Samples selected for analysis were SRC runs of June 16 and June 19, 1977. Relevant process information pertaining to these runs is given in Table 7. Organic and inorganic analyses were conducted separately. Figure 3 shows the analytical procedures followed.

TABLE 7. PROCESS INFORMATION

Date: June 16, 1977	
Load:	21 MW
Fuel Flow:	8,063 kg SRC/hr (17,775 lb/hr)
Heating Value:	7.464 MJ/kg SRC (15,602 Btu/lb)
Stack Gas Temperature:	166°C (331°F)
Sample Volume:	28,46 m^3 (1,005 DSCF)
Precipitator:	#1
Sample Port:	B (Outlet #1)
Precipitator Efficiency:	16.89%
Gas Flow, ESP #1 Outlet:	3,620 m^3/minute (127,858 ACFM)
Date: June 19, 1977	
Load:	7.5 MW
Fuel Flow:	3,379 kg SRC/hr (7,450 lb/hr)
Heating Value:	7.496 MJ/kg SRC (15,668 Btu/lb)
Stack Gas Temperature:	147°C (296°F)
Sample Volume:	30.16 m^3 (1,065 DSCF)
Precipitator:	#1
Sample Port:	B (Outlet #1)
Precipitator Efficiency:	45.68%
Gas Flow, ESP #1 Outlet:	2,005 m^3/minute (70,793 ACFM)

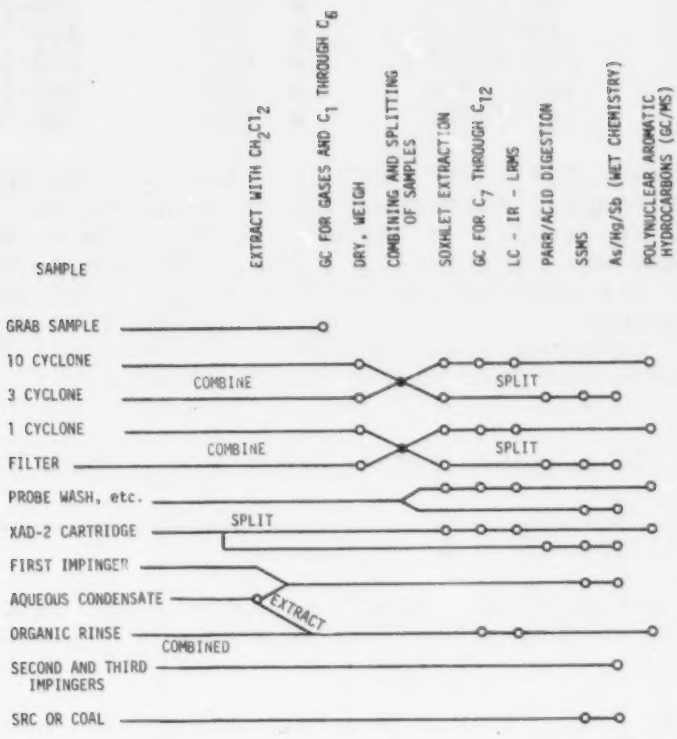


Figure 3. Analytical Procedures Followed in SASS Train Run Analysis

Organic Analysis--

Samples requiring solvent extraction for organic analyses were the XAD-2 resins and the cyclone and filter particulate samples. For XAD-2 resins, virtually all of the sample material was taken for extraction. A small portion of each XAD-2 resins was removed for inorganic analysis. Two composite particulate samples for each run were prepared, one by combining small portions of 10μ sample and 3μ sample, and the second by combining 1μ sample and filter sample. Methylene chloride was the solvent used in all extractions. Other required sample preparations included filtering the solids out of the probe rinses and concentrating all samples to 10 ml volumes.

C_7 through C_{16} gas chromatography--The gas chromatography was performed using the parameters and procedures specified by EPA for Level 1 analysis. On the instrument used, these parameters provided a lower detectable limit of approximately 0.2 $\mu g/m^3$. Analytical results are expressed in terms of the quantity of n-alkanes boiling in the following temperature ranges:

• C7	90-110°C	• C12	200-220°C
• C8	110-140°C	• C13	220-240°C
• C9	140-160°C	• C14	240-260°C
• C10	160-180°C	• C15	260-280°C
• C11	180-200°C	• C16	280-300°C

To calibrate the instrument for these C_7 through C_{16} boiling point ranges, chromatograms of n-alkane mixtures were obtained and a plot of normal boiling points versus retention times was constructed. The retention times corresponding to the appropriate boiling ranges were summed within each retention time interval in order to convert to quantities of components designated as n-alkanes. The results of these analyses are given in Table 8.

TABLE 8. GC ANALYSIS FOR C_7 THROUGH C_{16} HYDROCARBONS

	C_7		C_8		C_9		C_{10}		C_{11}	
	mg**	mg/m^3	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3
June 16, 1977	0*	0	3.73	0.12	0	0 z	0.53	0.20	1.82	0.06
June 19, 1977	0	0	2.52	0.09	1.51	0.05	0.80	0.03	2.68	0.09

	C_{12}		C_{13}		C_{14}		C_{15}		C_{16}	
	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3
June 16, 1977	0.85	0.03	0	0	0.11	0.004	0	0	0	0
June 19, 1977	1.29	0.05	0	0	1.08	0.04	0	0	0	0

* Zero values represent a detection limit of 0.007 mg.
**Total amount of compound detected in the samples.

For the particulate samples, all data for C_8 through C_{11} appeared to be significant, whereas for the probe rinse and XAD-2 module condensate extract plus module rinse samples probably none of the sample values were significant because of the high blank values.

Gravimetry and infrared spectrometry--To determine the nonvolatile contents of the samples, 1 ml aliquots were taken from each of the 10 ml concentrates and evaporated to dryness. The primary tool for understanding the significance of Level 1 gravimetry data is the infrared spectra

(IR), because the spectra can show qualitative differences between samples and blanks. The nonvolatile residues from the gravimetric procedure were scanned by an IR spectrometer, with the exception of the particulate extract samples, which all produced insufficient residues to be able to perform the IR analysis. The classes of compounds identified are listed in Tables 9 and 10. Due to the high blank values, none of the values appear significant.

Polynuclear aromatic hydrocarbons (PAH's) by combined gas chromatography/mass spectrometry (GC/MS)--For the GC/MS analysis, 1 ml aliquots of the 10 ml concentrated sample volumes were evaporated under a stream of inert gas and then brought up to a total volume of 2 ml, with 1 ml internal standard and 1 ml of benzene. The resulting solutions were analyzed with a Finnigan Model 4023 automated GC/MS instrument. The compounds in each sample were separated on a 1.8 meter x 2 millimeter ID glass column packed with three percent Dexsil 300 on 100-120 Chromosorb WHP. This column is operated from 100° to 295°C, programmed at 4°/min. The detection limit for this work was 0.1 g in the aliquots analyzed. The only polycyclic compound identified is most likely naphthalene ($C_{10}H_8$) or azulene (also $C_{10}H_8$). Because the naphthalene was also present in the blank, and because the blank also contained some of the styrenes, benzoates, and other compounds typically found as residual materials even in pre-cleaned XAD-2 resins; it was concluded that the samples did not contain organic materials significantly different from, or above, the blank materials.

Inorganic Analysis--

Two types of sample preparation were required for the inorganic analyses. The first was the Parr bomb combustion of the XAD-2 resin and SRC samples. For each of these samples, a 1-gram aliquot was combusted for Spark Source Mass Spectrometry (SSMS) and a 2-gram aliquot was combusted for the antimony, arsenic, and mercury analyses. All combustion solutions were made to a 100 ml volume. The Parr bomb combustion procedure utilized a quartz bomb liner and platinum electrodes and firing wire in order to minimize contamination of the samples from the stainless steel bomb.

The second type of preparation was the aqua regia digestion of particulate samples. Two composite particulate samples for each run were prepared, one by combining small portions of 10μ sample and 3μ sample, and the second by combining 1μ sample and filter sample. The samples were refluxed with constant-boiling aqua regia for six hours, filtered, and made up to 100 ml for antimony, arsenic, and mercury analyses. Because of their negligible organic content, the particulate samples did not require any

TABLE 9. IR EXAMINATION OF NONVOLATILE HYDROCARBONS
June 16, 1977

Sample	Classes of Compounds Identified
Probe Rinse	Esters of benzoic acid and other carboxylic acids, glycol, and phenolic resin (640 ppm)
XAD-2 Module Condensate Extract plus Module Rinse	Phthalic acid ester, other carxobylic acid esters, and phenolic resin (1,600 ppm)
XAD-2 Resin	Aliphatic carboxylates, glycol; minor-benzene derivatives (1,100 ppm)
Methylene Chloride Blank	Esters of benzoic acid and other carboxylic acids, and phenolic resin (3,700 ppm)
Methanol Blank	Phthalic acid ester, salt of carboxylic acid, and phenolic resin (500 ppm)
Methylene Chloride-Methanol Blank (50%-50%)	Esters of benzoic acid and other carboxylic acids, glycol, and phenolic resin (1,200 ppm)
XAD-2 Resin Blank	Trace of benzene derivatives (680 ppm)

TABLE 10. IR EXAMINATION OF NONVOLATILE HYDROCARBONS
June 19, 1977

Sample	Classes of Compounds Identified
Probe Rinse	Esters of benzoic acid and other carboxylic acids, glycol, and phenolic resin (660 ppm)
XAD-2 Module Condensate Extract plus Module Rinse	Major - aliphatic carboxylates; minor - phthalates, benzoates, and phenolic resin (1,700 ppm)
XAD-2 Resin	Esters of aliphatic carboxylic acid and benzoic acid, glycol, and traces of benzene derivatives (700 ppm)
Methylene Chloride Blank	Esters of benzoic acid and other carboxylic acids, and phenolic resin (3,700 ppm)
Methanol Blank	Phthalic acid ester, salt of carboxylic acid, and phenolic resin (500 ppm)
Methylene Chloride - Methanol Blank (50%-50%)	Esters of benzoic acid and other carboxylic acids, glycol, and phenolic resin (1,200 ppm)
XAD-2 Resin Blank	Trace of benzene derivatives (680 ppm)

preparation for the SSMS analysis. The condensates and impingers also required no preparation.

Antimony, arsenic, and mercury elemental analyses--The specific elemental analyses were performed using the expanded and modified Level 1 procedures compiled by Research Triangle Institute at EPA's direction. Briefly, these methods are as follows:

- Mercury - reduction to elemental mercury with stannous chloride, sparging through a detection cell and measurement of the mercury at 253.7 nm.
- Arsenic - reduction to the hydride with stannous chloride and metallic zinc, sparging into an argon-hydrogen flame in an atomic absorption spectrophotometry (AA) instrument and measurement of the arsenic at 193.7 nm.
- Antimony - reaction with a series of reagants to form stibine, sparging into a hydrogen diffusion flame in an AA instrument, and measurement of the antimony at 217.6 nm.

The results obtained by analyzing the particulate and XAD-2 resin samples are reported in Table 11.

TABLE 11. TOTAL HG, AS, AND SB IN PARTICULATES AND XAD-2 RESIN

	Hg	As	Sb
June 16, 1977	191.53 µg* ($6.73\ \mu g/m^3$)	2,240 µg ($78.72\ \mu g/m^3$)	52 µg ($1.89\ \mu g/m^3$)
June 19, 1977	351.61 µg ($11.66\ \mu g/m^3$)	650 µg ($21.55\ \mu g/m^3$)	53 µg ($1.76\ \mu g/m^3$)
SRC Sample	45 ppb	14 ppm	ND**

* - Total amount of element detected in the samples.
**ND - None detected, antimony detection limit is 0.005 ppm.

Spark source mass spectrometry--The SSMS analysis was performed by Commercial Testing and Engineering Co. of Golden, Colorado. The results for the SASS train and SRC samples are presented in Tables 12 and 13. During the SSMS analysis, several of the elements were found to be mass constituents, and had too high a concentration to be

TABLE 12. SSMS ELEMENTAL ANALYSIS OF SASS TRAIN SAMPLES

Constituent	June 16, 1977 μg*	June 16, 1977 μg/m^3	June 19, 1977 μg*	June 19, 1977 μg/m^3
Uranium	958	34	581	19
Thorium	674	24	250	8
Lead	141	5	78	3
Thallium	13	0.5	15	0.5
Platinum	5	0.2	7	0.2
Rhenium	5	0.2	4	0.1
Tungsten	73	3	36	1
Tantalum	30	1	31	1
Hafnium	73	3	31	1
Lutetium	16	0.6	9	0.3
Ytterbium	121	4	47	2
Thulium	15	0.5	5	0.2
Erbium	96	3	15	0.5
Holmium	121	4	31	1
Dysprosium	212	7	47	2
Terbium	48	2	10	0.3
Gadolinium	129	5	31	1
Europium	65	2	14	0.5
Samarium	322	11	64	2
Neodymium	468	16	68	2
Praseodymium	138	5	36	1
Cerium	584	21	233	8
Lanthanum	485	17	176	6
Barium	22,200**	780	1,333	44
Cesium	52	2	6	0.2
Iodine	16	0.6	31	1
Tellurium	11	0.4	7	0.2
Antimony	66	2	47	2
Tin	230	8	97	3
Cadmium	38	1	32	1
Silver	6	0.2	123**	4
Molybdenum	772	27	505	17
Niobium	1,790	63	904	30

(continued)

TABLE 12. (continued)

	June 16, 1977		June 19, 1977	
	μg*	μg/m^3	μg*	μg/m^3
Zirconium	8,400**	295	3,416	113
Yttrium	3,355	118	1,258	42
Strontium	4,254**	149	2,054	68
Rubidium	115	4	43	1
Bromine	80	3	890	30
Selenium	296	10	15	2
Arsenic	1,611	57	1,303	43
Germanium	218	8	352	12
Gallium	803	28	881	29
Zinc	1,111	39	2,636	87
Copper	1,252	44	1,230**	41
Nickel	2,654	93	1,137	38
Cobalt	525	18	243	8
Iron	2,002,018**	70,345	1,201,866**	39,850
Manganese	8,859	311	4,830**	160
Chromium	2,004,011**	70,415	11,200**	371
Vanadium	1,008,338**	35,430	7,260**	241
Titanium	1,302,045**	45,750	400,826**	13,290
Scandium	852	30	601	20
Calcium	4,008,022**	140,830	1,502,873**	49,830
Potassium	1,000,084**	35,140	24,060**	798
Chlorine	447	16	2,130**	71
Sulfur	620,000**	21,785	22,020**	730
Phosphorus	1,030,252**	36,200	20,100**	666
Silicon	600,506**	21,100	330,252**	10,950
Sodium	9,420**	331	11,010**	365
Fluorine	541	19	719	24
Boron	7,300	257	8,727	289
Beryllium	394	14	300	10
Lithium	141	5	159	5
Aluminum	6,008**	211	4,403**	146
Magnesium	600,506**	21,100	330,252**	10,950

* Total amount of element detected in the samples of particulates.
**Mass Constituent (MC) - too high in concentration to be quantified. Values reported represent the lower estimated limit.

TABLE 13. SSMS ANALYSIS OF SRC SAMPLE

Element	Concentration μg/g**	Element	Concentration μg/g**
Uranium	1	Nickel	5
Lead	5	Cobalt	0.2
Platinum	0.9	Iron	30
Cerium	0.2	Manganese	3
Lanthanum	0.3	Chromium	3
Barium	4	Vanadium	2
Cesium	0.5*	Titanium	30
Silver	0.2	Scandium	0.1
Molybdenum	6	Calcium	200
Niobium	0.3	Potassium	20
Zirconium	2	Chlorine	3
Yttrium	0.9	Sulfur	30
Strontium	2	Phosphorus	9
Rubidium	0.5	Silicon	300
Selenium	0.6	Aluminum	10
Arsenic	0.5	Magnesium	40
Germanium	0.1	Sodium	30
Gallium	0.4	Fluorine	40
Zinc	8	Boron	10
Copper	4	Beryllium	0.2
		Lithium	0.2

* Elements designated as "≤" were identified, but because of their low concentrations, could not be quantified as accurately.
**Concentration of element in μg per gram of SRC sample.

quantified. For these elements, the lower estimated limits are reported.

Interpretation of Results--

Additional analyses, based on the results of Part I, were to be performed under Part II to provide a comparison of coal and SRC flue gases. The analytical results from the organic analysis indicated that only volatile C_7 through C_{12} hydrocarbons were present in appreciable quantities. Nonvolatile hydrocarbons and polynuclear aromatic hydrocarbons were not found in significant quantities above the blank values. It was therefore decided to analyze two additional SASS train runs, one SRC and one coal, for C_7 through C_{12} hydrocarbons to provide a comparison of the organic content of the respective flue gases.

Based upon the SSMS results, 17 elements were selected to be analyzed by Atomic Absorption Spectrophotometry for the two additional SASS train runs. Elements selected included several of the MC elements, and other elements of interest present in significant quantities. Table 14 lists the 17 elements selected for analysis.

TABLE 14. ELEMENTS SELECTED FOR PART II INORGANIC ANALYSIS

Mass Constituents (MC)	Elements of Interest
Aluminum	Antimony
Barium	Arsenic
Chromium	Boron
Copper	Lead
Iron	Mercury
Magnesium	Nickel
Manganese	Thorium
Vanadium	Uranium
	Zinc

Part II

In Part II, two additional SASS train runs were analyzed by the Hittman laboratory. Samples selected for analysis included a coal run of May 25, 1977, an SRC run of June 14, 1977, and respective coal and SRC grab samples. Relevant process information is given in Table 15.

TABLE 15. PROCESS INFORMATION

Date: May 25, 1977	
Load:	14 MW
Fuel Flow:	6,940 kg coal/hr (15,300 lb/hr)
Heating Value:	7.007 MJ/kg (14,648 Btu/lb)
Stack Gas Temperature:	147°C (296°F)
Sample Volume:	29.65 m^3 (1,047 DSCF)
Precipitator:	#1
Sample Port:	B (Outlet #1)
Precipitator Efficiency:	94.81%
Gas Flow, ESP #1 Outlet:	3,002 m^3/minute (105,997 ACFM)
Date: June 14, 1977	
Load:	14 MW
Fuel Flow:	5,460 kg SRC/hr (12,038 lb/hr)
Heating Value:	7.525 MJ/kg (15,729 Btu/lb)
Stack Gas Temperature:	144°C (291°F)
Sample Volume:	28.60 m^3 (1,010 DSCF)
Precipitator:	#1
Sample Port:	B (Outlet #1)
Precipitator Efficiency:	21.96%
Gas Flow, ESP #1 Outlet:	3,076 m^3/minute (108,632 ACFM)

Organic Analysis--

Samples were prepared as in Part I, Organic Analysis, and run on the Packard Model 419 Becker gas chromatograph. Analytical results are again expressed in terms of the quantity of n-alkanes boiling in the following temperature ranges:

- C_7 90-110°C
- C_8 110-140°C
- C_9 140-160°C
- C_{10} 160-180°C
- C_{11} 180-200°C
- C_{12} 200-220°C

The results of these analyses are given in Table 16.

TABLE 16. GC ANALYSIS FOR C_7 THROUGH C_{12} HYDROCARBONS

	C_7		C_8		C_9	
	mg*	mg/m^3	mg	mg/m^3	mg	mg/m^3
Coal-May 25, 1977	17.34	0.58	T	-----	10.21	0.34
SRC-June 14, 1977	ND	-----	3.09	0.11	8.60	0.30

	C_{10}		C_{11}		C_{12}	
	mg	mg/m^3	mg	mg/m^3	mg	mg/m^3
Coal-May 25, 1977	2.45	0.08	15.30	0.52	16.83	0.57
SRC-June 14, 1977	5.36	0.19	23.97	0.84	14.10	0.49
ND - None Detected						
T - Trace (≤1 ppm)						

* - Amount of compound detected.

Inorganic Analysis--

Samples were prepared as in Part I, Inorganic Analysis, and run on the Perkin Elmer Model 603 Atomic Absorption Spectrophotometer. The results of these analyses are reported in Table 17.

TABLE 17. AA ANALYSIS FOR INORGANICS

Constituent	Coal SASS train run May 25, 1977		SRC SASS train run June 14, 1977		Coal grab samples May 25, 1977		SRC grab samples June 14, 1977	
	µg*	µg/m^3	µg*	µg/m^3	Sample I µg/g**	Sample II µg/g**	Sample I µg/g**	Sample II µg/g**
Aluminum	24,016	809.98	6,150	215.03	5,223.0	4,506.0	60.0	95.0
Antimony	135	4.55	102	3.57	1.7	--	0.1	--
Arsenic	69	2.32	41	1.42	2.9	--	1.8	--
Barium	1,430	48.23	335	11.71	58.0	--	2.0	--
Boron	7	0.24	56	1.95	ND	--	0.2	0.5
Chromium	1,694	57.13	475	16.61	13.0	4.5	4.0	6.0
Copper	246	8.30	18	0.63	16.0	14.0	1.2	1.5
Lead	185	6.24	40	1.40	9.0	7.5	0.5	ND
Iron	37,624	1,268.94	22,869	799.62	3,352.0	2,503.0	187.0	250.0
Magnesium	4,096	138.15	1,656	57.90	340.0	370.0	8.0	12.0
Manganese	884	29.81	1,789	62.55	21.0	21.0	14.5	18.0
Mercury	17	0.57	59	2.06	0.3	--	0.8	--
Nickel	2,441	82.33	385	13.46	12.0	10.5	2.0	2.3
Thorium	236	7.96	31	1.08	4.7	4.2	5.0	3.7
Uranium	6	0.20	101	3.53	1.3	1.4	0.8	1.3
Vanadium	364	12.28	1,269	5.91	24.1	20.0	11.4	10.9
Zinc	382	12.88	258	9.02	12.5	50.0	6.5	7.5

ND - None Detected
* - Total amount of element detected in sample
** - Concentration of element per gram of sample

SECTION 5

COMPARISON OF AIR EMISSIONS

Prior to attempting to compare the emissions resulting from the combustion of SRC and coal at Plant Mitchell, several factors must be considered. First, the results obtained from the SRC analyses conducted under Part I should not be used for comparison purposes. The load conditions during the period of sampling (7.5 MW and 21 MW) do not compare with the load conditions of the coal run analyzed under Part II (14 MW). Also, the difficulty in quantifying the MC elements poses serious questions about the accuracy of the SSMS results. Results obtained from Part I analyses were used only to provide an indication of the presence or absence of constituents in SRC flue gas streams. Only analytical results from Part II should be used for the comparison of SRC and coal air emissions.

The second factor which must be considered is the difference in the efficiency of precipitator #1 between when SRC and coal are fired. For the coal run of May 25, 1977 and the SRC run of June 14, 1977, precipitator efficiencies were 94.81 and 21.96 percent respectively. Precipitator #1 is an old (1946) Research Cottrell unit. During the latter part of Phase III, precipitator #3 was used, and the collection efficiency for SRC increased to approximately 95 percent. Therefore, it should be noted that the particulate air emissions given in this report resulting from the combustion of SRC may be assumed to represent maximum values. The precipitator efficiency had no impact on gaseous emissions (organics, SO_x, NO_x, etc.). For further information concerning precipitator efficiency during the combustion test, readers are referred to a report by Southern Research Institute, Evaluation of Electrostatic Precipitator at Plant Mitchell, January 1978, under EPA Contract No. 68-02-2610.

ORGANICS

Table 18 shows the comparison of the C_7 through C_{12} hydrocarbons present in the combustion flue gases for SRC and coal. Detectable quantities of all C_7 through C_{12} hydrocarbons were present in both coal and SRC flue gases.

However, during combustion of SRC, C_7, C_9 and C_{12} hydrocarbon emissions decreased, while C_8, C_{10} and C_{11} emissions increased. The comparison of coal and SRC emissions offers no clear indication of the effects on C_7 through C_{12} emissions by the substitution of SRC for low sulfur coal.

TABLE 18. ORGANIC AIR EMISSIONS FOR COAL AND SRC

Hydrocarbon	Coal May 25, 1977 $\mu g/m^3$	SRC June 14, 1977 $\mu g/m^3$
C_7	0.58	ND
C_8	T	0.11
C_9	0.34	0.30
C_{10}	0.08	0.19
C_{11}	0.52	0.84
C_{12}	0.57	0.49

ND - None Detected
T - Trace

INORGANICS

The resulting air emissions from the combustion of coal on May 25, 1977 and SRC on June 14, 1977 at Plant Mitchell, are shown in Table 19. The coal used to produce the SRC was not from the same source as the coal fired on May 25, 1977. The quantity of minerals present in the respective coal have a direct impact on the resulting air emissions. During coal combustion highly volatile trace elements may appear in combustion gases. During solvent refining along with sulfur and ash reduction some highly volatile trace elements may also be removed from coal. Due to this reason when SRC is burned lower concentrations of trace elements generally appear in the combustion gases. As shown in Table 19 concentrations of most of the trace elements in combustion gases from SRC derived from high sulfur coal are lower than those resulting from direct combustion of low sulfur coal.

TABLE 19. INORGANIC AIR EMISSIONS FOR COAL AND SRC

Constituent	Coal May 25, 1977 $\mu g/m^3$*	SRC June 14, 1977 $\mu g/m^3$*
Aluminum	809.98	215.03
Antimony	4.55	3.57
Arsenic	2.32	1.42
Barium	48.23	11.71
Boron	0.24	1.95
Chromium	57.13	16.61
Copper	8.30	0.63
Lead	6.24	1.40
Iron	1,268.94	799.62
Magnesium	138.15	57.60
Manganese	29.81	62.55
Mercury	0.57	2.06
Nickel	82.33	13.46
Thorium	7.96	1.08
Uranium	0.20	3.53
Vanadium	12.28	5.91
Zinc	12.88	9.02

*The concentrations are based on amount of a constituent detected in the total particulates collected.

SO_2 AND NO_x

The values of SO_2 and NO_x in the SRC and coal combustion gases obtained from continuous analyzers are shown in Table 20. The emission of SO_2 is reduced approximately 37 percent, and NO_x by 12 percent, when SRC is fired. These

TABLE 20. SO_2 AND NO_x EMISSIONS FOR COAL AND SRC

Load Condition	Coal Date	Coal SO_2*		Coal NO_x*		SRC Date	SRC SO_2*		SRC NO_x*		% Reduction SO_2	% Reduction NO_x
Low (7.5 MW)	5/26/77	0.645	(1.50)	0.198	(0.46)	6/15/77	0.520	(1.21)	0.201	(0.48)	19.33	-4.35
Low	5/31/77	1.023	(2.38)	0.224	(0.52)	6/18/77	0.452	(1.05)	0.176	(0.41)	55.88	21.15
Low	6/01/77	0.598	(1.39)	0.215	(0.50)	6/19/77	0.486	(1.13)	0.176	(0.41)	18.71	18.00
Average		0.757	(1.76)	0.211	(0.49)		0.486	(1.13)	0.185	(0.43)	35.80	12.24
Medium (14 MW)	5/25/77	0.800	(1.86)	0.194	(0.45)	6/14/77	0.439	(1.02)	0.194	(0.45)	45.16	0.00
Medium	5/29/77	0.791	(1.84)	0.215	(0.50)	6/20/77	0.477	(1.11)	0.211	(0.49)	39.67	2.00
Medium	5/30/77	0.791	(1.84)	0.215	(0.50)	6/21/77	0.447	(1.04)	0.194	(0.45)	43.48	10.00
Average		0.796	(1.85)	0.201	(0.48)		0.456	(1.06)	0.198	(0.46)	42.70	4.17
Full (21 MW)	5/24/77	1.002	(2.33)	0.215	(0.50)	6/13/77	0.426	(0.99)	0.176	(0.41)	57.51	18.00
Full	5/27/77	0.443	(1.03)	0.201	(0.48)	6/16/77	0.412	(0.97)	0.168	(0.39)	5.83	18.75
Full	5/28/77	0.456	(1.06)	0.220	(0.51)	6/17/77	0.434	(1.01)	0.172	(0.40)	4.72	21.57
Average			(1.47)	0.215	(0.50)			(0.99)	0.172	(0.40)	32.65	20.00
Total Average		0.727	1.69	0.211	0.49		0.426	(1.06)	0.185	(0.43)	37.28	12.24

*Values are in kg/GJ and ($lb/10^6$ Btu)

values represent substantial reductions in total SO_2 and NO_x emissions. However, during the combustion test abnormally high excess air was used, which would have an effect of lowering NO_x. The combustion test should therefore be run under normal conditions to obtain the NO_x emissions data.

SECTION 6

ASSESSMENT OF AIR EMISSIONS

ORGANICS

The release of organic constituents to the air via the combustion of SRC is not an area of major environmental concern. The objective of the combustion process is to convert all carbon present in the feedstock to carbon dioxide. Therefore, significant quantities of organic constituents will only be discharged during incomplete combustion. This is not the case with today's sophisticated boiler operations. The emissions of C_7 through C_{12} hydrocarbons during the combustion of SRC do not appear to differ significantly from the direct combustion of coal. Therefore, these emissions are not at present an area of major environmental concern. Also, no carcinogenic PAH's were found in the SRC flue gases.

INORGANICS

The method used to assess the impact of the inorganic air emissions resulting from the combustion of SRC will be the Multimedia Environmental Goals (MEG's). MEG's, currently being developed by EPA, are levels of significant contaminants or degradents (in ambient air, water, or land, or in emissions or effluents conveyed to the ambient media) that are judged to be (1) appropriate for preventing certain negative effects in the surrounding populations or ecosystems, and (2) representative of the control limits achievable through technology. MEG's are divided into two distinct sections, Ambient Level Goals and Emission Level Goals, and have been published for more than 200 compounds. The November 1977 version of the MEG's chart is shown in Figure 4.

Emission Level Goals presented in the top half of the MEG's chart pertain to gaseous emissions to the air, aqueous effluents to water, and solid waste to be disposed to land. Only the gaseous emissions to the air are addressed by this report.

MULTIMEDIA ENVIRONMENTAL GOALS

EMISSION LEVEL GOALS							
	I. Based on Best Technology		II. Based on Ambient Factors				
	A. Existing Standards	B. Developing Technology	A. Minimum Acute Toxicity Effluent		B. Ambient Level Goal*		C. Elimination of Discharge
	NSPS, BPT, BAT	Engineering Estimates (R&D Goals)	Based on Health Effects	Based on Ecological Effects	Based on Health Effects	Based on Ecological Effects	Natural Background*
Air, $\mu g/m^3$ (ppm Vol)							
Water, $\mu g/l$ (ppm Wt)							
Land, $\mu g/g$ (ppm Wt)							

*To be multiplied by dilution factor

AMBIENT LEVEL GOALS					
	I. Current or Proposed Ambient Standards or Criteria		II. Toxicity Based Estimated Permissible Concentration		III. Zero Threshold Pollutants Estimated Permissible Concentration
	A. Based on Health Effects	B. Based on Ecological Effects	A. Based on Health Effects	B. Based on Ecological Effects	Based on Health Effects
Air, $\mu g/m^3$ (ppm Vol)					
Water, $\mu g/l$ (ppm Wt)					
Land, $\mu g/g$ (ppm Wt)					

Figure 4. MEG Chart, November 1977 Version

Emission Level Goals based on best technology have not as yet been developed. Emission Level Goals based on ambient factors have been developed for more than 200 compounds and include consideration of:

(1) Minimum Acute Toxicity Effluents (MATE's) - concentrations of pollutants in undiluted emission streams that will not adversely affect those persons or ecological systems exposed for short periods of time.

(2) Ambient Level Goals, i.e., Estimated Permissible Concentrations (EPC's) - concentrations of pollutants in emission streams which, after dispersion, will not cause the level of contamination in the ambient media to exceed a safe continuous exposure concentration.

(3) Elimination of Discharge (EOD) - concentrations of pollutants in emission streams which, after dilution, will not cause the level of contamination to exceed levels measured as "natural background."

Columns are provided on the MEG chart under Emission Level Goals for each of these. For additional information concerning MEG's, readers are referred to Multimedia Environmental Goals for Environmental Assessment, Volumes 1 and 2, (EPA-600/7-77-136a and b).

Table 21 provides a comparison of SRC air emissions with the MEG values for the inorganic elements analyzed in Part II. Chromium is the only element which fails to meet the MATE value. Zinc and boron are the only elements which meet the ambient level goal values. However, as shown in the table, the MEG value for zinc is not much lower than ambient level and if sampling and analytical uncertainties were added, zinc would not meet the goal. None of the elements meets the elimination of discharge values.

SO_2 AND NO_x

One method of assessing the environmental impact of SO_2 and NO_x emissions from the combustion of SRC is by comparison with existing New Source Performance Standards (NSPS). The existing NSPS for SO_2 and NO_x are 0.52 and 0.30 kg/GJ (1.2 and 0.7 lb/10^6 Btu) input, respectively. The average emission rates for SO_2 and NO_x during the combustion of SRC at Plant Mitchell were 0.46 and 0.19 kg/GJ (1.06 and 0.43 lb/10^6 Btu) respectively, well within the existing standards. However, EPA is currently considering reducing

TABLE 21. COMPARISON OF SRC AIR EMISSIONS WITH MEG's

Constituent	Minimum Acute Toxicity Effluent		Ambient Level Goal		Elimination of Discharge	SRC
	Based on Health Effects*	Based on Ecological Effects*	Based on Health Effects*	Based on Ecological Effects*	Natural Background*	June 14, 1977*
Aluminum	5,200	---	12.6	---	---	215.03
Antimony	500	---	1.2	---	0.007	3.57
Arsenic	2	---	0.005	---	0.00005	1.42
Barium	500	---	1	---	0	11.71
Boron	3,100	---	74	---	---	1.95
Chromium	1	---	0.002	---	0.012-0.001	16.61
Copper	200	---	0.5	---	0.01-0.41	0.63
Iron	---	---	---	---	___	799.62
Lead	150	---	0.36	---	0.002-0.47	1.40
Magnesium	6,000	---	14	---	1.4-800	57.90
Manganese	5,000	---	12	---	0.005-0.047	62.55
Mercury	50	10	0.01	1	---	2.06
Nickel	15	---	0.035	---	0.0006-0.021	13.46
Thorium	---	---	---	---	---	1.08
Uranium	9	---	0.5	---	---	3.53
Vanadium	500	1	1.2	0.1	0.005-0.024	5.91
Zinc	4,000	---	9.5	---	0.013-0.2	9.02

* Values are in $\mu g/m^3$

--- Values have not yet been developed

the SO_2 NSPS to 0.26 kg/GJ (0.6 lb/10^6 Btu). It is questionable whether SRC can meet this standard.

As discussed earlier abnormally high excess air was used during the combustion test. Table 4 shows high concentrations (10.6 to 14.8%) of free oxygen in the flue gas. This high oxygen content is equivalent to about 240 to 100% excess air. The combination of molecular N_2 and O_2 by thermal fixation is an equilibrium reaction with the final concentration of NO primarily dependent on the reaction temperature. The higher the temperature the higher the equilibrium concentration of NO in presence of excess air. However, at very high excess air the temperature decreases and so does the concentration of NO.

BIBLIOGRAPHY

Cleland, J.G. and G.L. Kingsbury. 1977. Multimedia Environmental Goals for Environmental Assessment, Volumes I and II. EPA-600/7-77-136a and b. U.S. Environmental Protection Agency, Washington, D.C. 148 pp.

Hamersma, J.W., S.L. Reynolds, and R.F. Maddalone. 1976. IERL-RTP Procedures Manual: Level 1 Environmental Assessment. EPA-600/2-76-160a. U.S. Environmental Protection Agency, Washington, D.C. 131 pp.

Koralek, C.S. and V.B. May. Flue Gas Sampling during the Combustion of Solvent Refined Coal in a Utility Boiler. Paper presented at Third Symposium on Environmental Aspects of Fuel Conversion Technology, III. EPA-600/7-78-063. Hollywood, Florida, September 13, 1977.

Nichols, G.B., S.M. Banks, J.R. McDonald, W.J. Barrett, W.R. Dickson, and J.E. Paul. 1978. Evaluation of Electrostatic Precipitator at Plant Mitchell. Contract No. 68-02-2610. EPA-600/7-78-129. U.S. Environmental Protection Agency, Washington, D.C. 48 pp.

Rubin, E.S. and F.C. McMichael. Impact of Regulations on Coal Conversion Plants. Environmental Science and Technology, Vol. 9, No. 2, February 1975. 112-117 pp.